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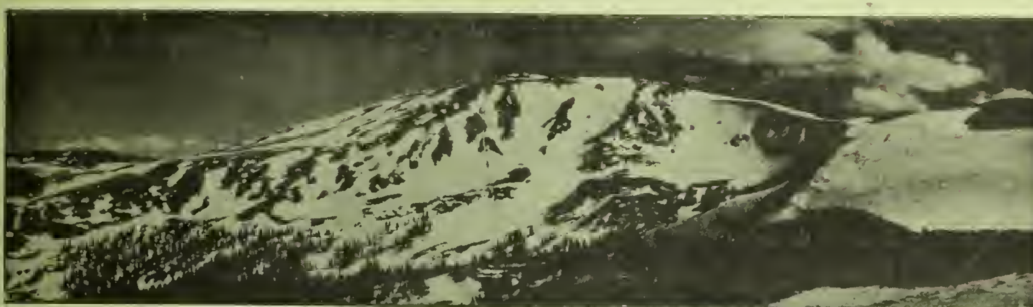

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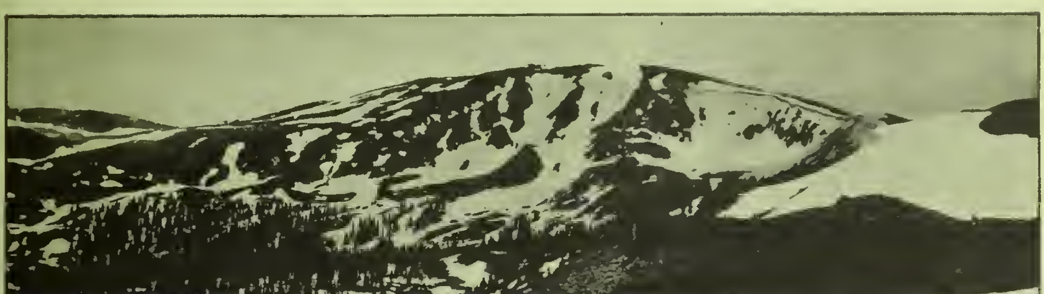

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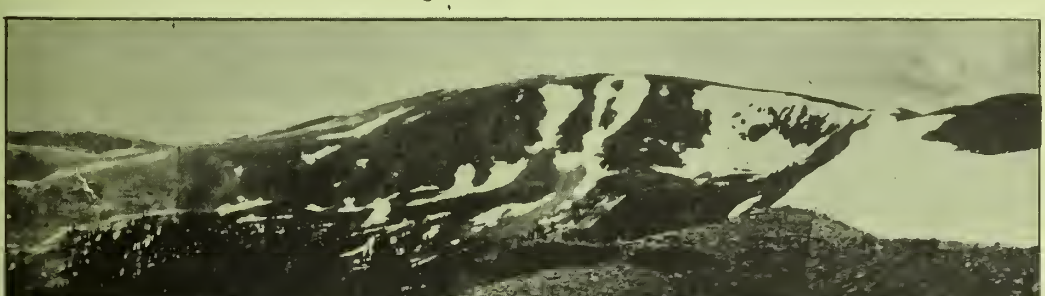


July 3

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Raymond Price, Director Fort Collins, Colorado

U. S. FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE

STREAMFLOW IN RELATION TO EXTENT OF SNOW COVER IN CENTRAL COLORADO 1/

By

H. E. Brown and E. G. Dunford, Foresters 2/

INTRODUCTION

The bulk of streamflow from the Colorado Rocky Mountains is produced by spring snowmelt. The study reported here was made to investigate the relation between streamflow and the area of snow cover during the melting period. Field work was done during the spring of 1950 at the Fraser Experimental Forest near Fraser, Colorado, as a part of the cooperative snow investigations of the Bureau of Reclamation and the Forest Service.

Other investigations of snow cover have been made in western United States from 1946 to the present time. Among these is the work of the Corps of Engineers at the Central Sierra Snow Laboratory in California, and at the Upper Columbia Snow Laboratory in Montana. Although the objectives and methods used in this study are similar in some respects to those used by the Corps of Engineers, the projects were carried out independently.

THE OBSERVATION AREA

Observations were made on the watershed of St. Louis Creek, a part of the Colorado River drainage. The area of the watershed is 32.8 square miles, and elevations range from 9,000 to 12,790 feet. About one-fourth of the watershed is above timberline, and the remainder is forested, with the exception of a few small meadows along the stream courses. The forest types are lodgepole pine and spruce-fir. Lodgepole pine grows at the lower elevations and on south slopes at intermediate elevations, and the spruce-fir forest occurs at higher elevations.

1/ This study was a part of the Cooperative Snow Investigations with the U. S. Department of the Interior, Bureau of Reclamation.

2/ Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, maintains central headquarters at Fort Collins, Colorado, in cooperation with Colorado A & M College. In 1952 Mr. Dunford transferred to the Pacific Northwest Forest and Range Experiment Station.

During the spring of 1950, climatic conditions were about average. Average daily temperatures ranged from 13° to 48° F. for the period April 1 to July 12. The maximum snow pack over the watershed had an average water content of 16.5 inches.

SNOW COVER MAPPING

A base map was constructed from aerial photographs at a scale of 3.13 inches per mile and overlays were used to record snow cover at the time of each observation. Snow cover was mapped 15 times to record progress of melting. Three high observation points were used to obtain a view of the entire drainage. As a general rule, the observations were made weekly except after fresh snowfall when the observation was delayed a few days to allow the new snow to melt sufficiently to show the general disappearance pattern. Snow cover was estimated with the aid of binoculars to the nearest 5 percent. Panoramic photographs were also taken at the time of each observation.

In order to systematize observations, individual tributary drainages were subdivided into 16 compartments as shown by figure 1. Percentage of snow cover in each compartment was estimated and recorded in note form. In the office, the recorded amount of snow cover in each compartment was placed on an overlay map to show the distribution of snow cover. A simple weighted average snow cover for the entire watershed was then determined, based on compartment size and extent of snow cover in each compartment.

SNOW COVER DURING THE MELTING SEASON

Before the first of April the entire watershed was covered with snow, except for areas too steep to hold snow or so exposed that wind kept them blown clear. The first areal disappearance of snow due to melting started in early April at the lowest elevations on south aspects. Snow disappearance was limited to these sites until the middle of May. From then until mid-June, extensive bare areas appeared on north aspects at low elevations and south aspects at high elevations. Snow on east and west aspects disappeared after that on south but before that on north aspects. In the latter part of June, snow disappeared from north aspects at high elevations and from those alpine areas without deep drifts. By mid-July the only snow remaining was in deep alpine drifts such as those in the steep cirques at the head of each major drainage. A few drifts persisted throughout the summer.

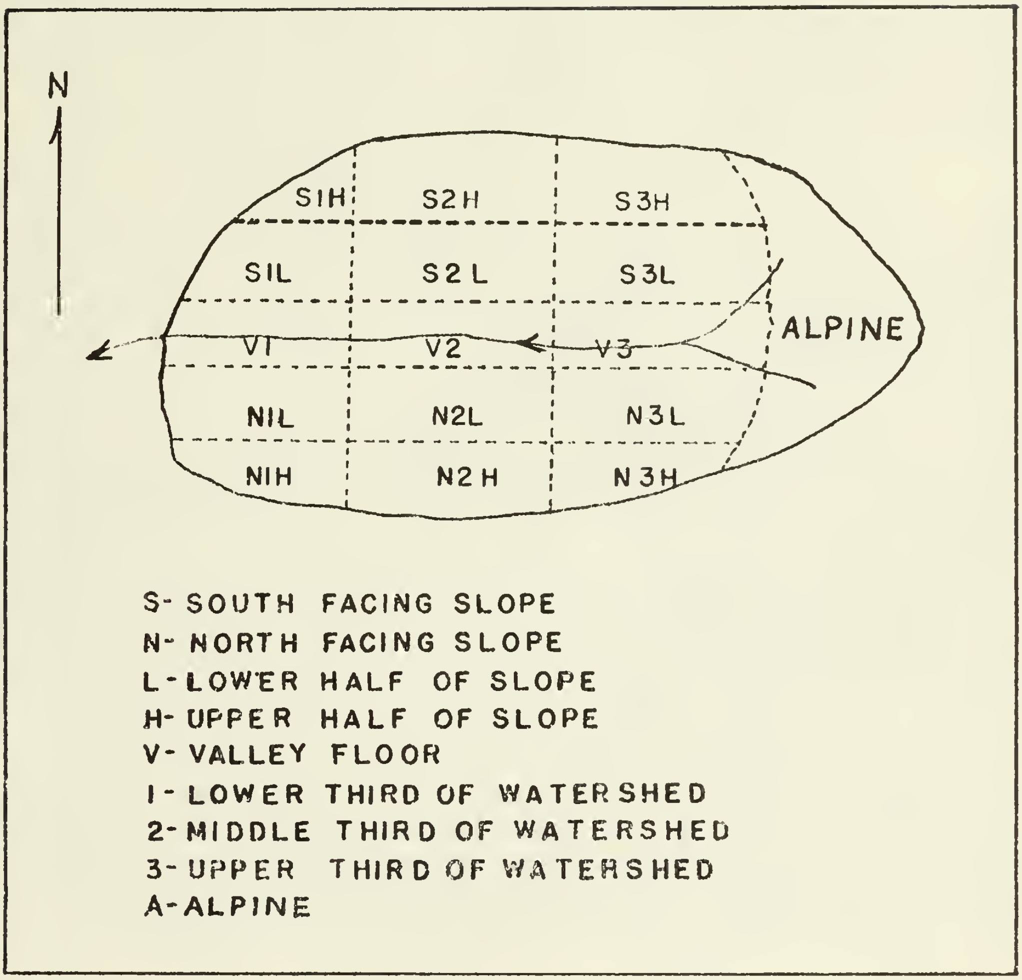


Figure 1.-- Method of dividing tributary watersheds into topographic compartments to record snow cover.

RELATION TO STREAMFLOW

Probably the most significant finding of this study was evidence that a close relation exists between streamflow and snow cover. This relation is demonstrated by figure 2A. A close correlation between snow disappearance and streamflow during the melt period is indicated by the near coincidence of these curves.

In figure 2B the St. Louis Creek hydrograph for the 1950 snowmelt season has been plotted to show how rate of snow disappearance is reflected in the mean daily stream discharge. A second plotting of the hydrograph is made in figure 3, together with generalized versions of five snow cover overlays. Here the relation can be seen between the retreating snow mantle and the snowmelt hydrograph.

A comparison of snow disappearance with streamflow, as illustrated in figures 2 and 3, can best be made beginning in late March. At that time snow cover on the watershed was nearly complete and St. Louis Creek was flowing at base level (9 c.f.s.). Then in early April as the first bare areas appeared at low elevations, the stream began a very gradual rise. Both bare area and streamflow continued to increase very slowly until about May 9, at which time the total bare area was 8 percent, and the daily discharge had risen to about 20 c.f.s. Then the snow began to disappear more rapidly, and about 35 percent of the area was bare by early June. During this period of moderate melt, the rate of discharge fluctuated widely but made an overall rise to 140 c.f.s. After June 9 the rate of snow disappearance was consistently high until July 3, at which time practically all snow was gone from the watershed. During this relatively short time (roughly one-fourth of the melt period) 55 percent of the watershed lost its snow, and 57 percent of the cumulative discharge was recorded at the stream gage. It was also during this period, on June 17, that the peak daily discharge of 263 c.f.s. was reached. On that date 58 percent of the watershed was bare of snow and practically all of the snow below the 10,000-foot level had melted. After July 3 the rate of snow disappearance dropped off quickly because the only snow remaining was on sheltered sites at high elevations. The rate of cumulative stream discharge began to level off at the same time.

RELATION OF AREAL AND VOLUMETRIC ESTIMATES OF SNOW COVER

The volume of water in the snow pack was estimated from snow tube samples taken on five snow courses on the St. Louis watershed. Ten samples were taken from each course on March 30, April 30, and June 2. Measurements were averaged for each date and expressed as a percentage of the March 30 value. Figure 4 shows a comparison between these percentages and the percent of areal snow cover on the watershed. The curves shown in figures 3 and 4 indicate that the extent of snow cover is more closely related to melt-period streamflow than is the current water content of snow. The initial spring

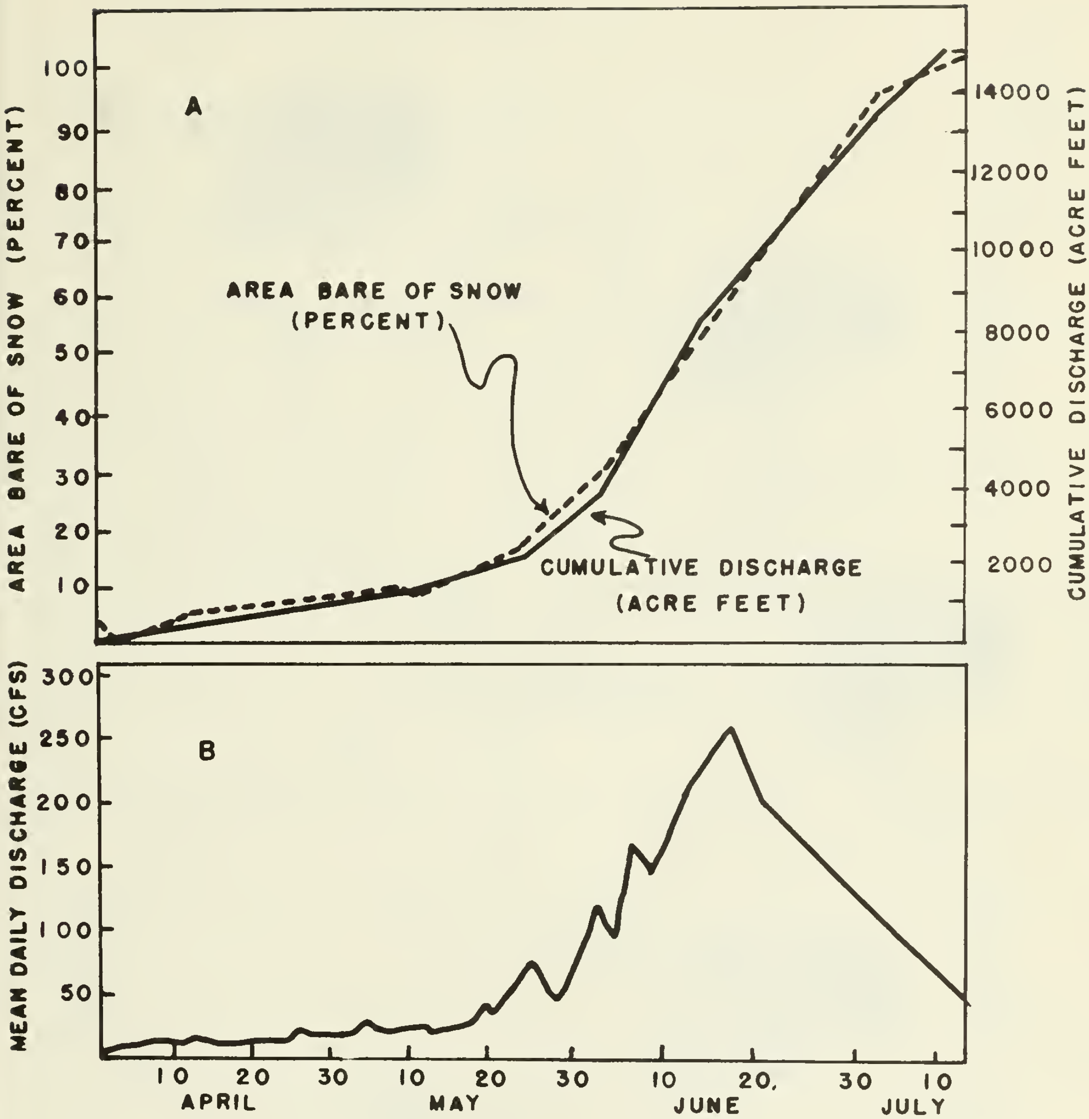
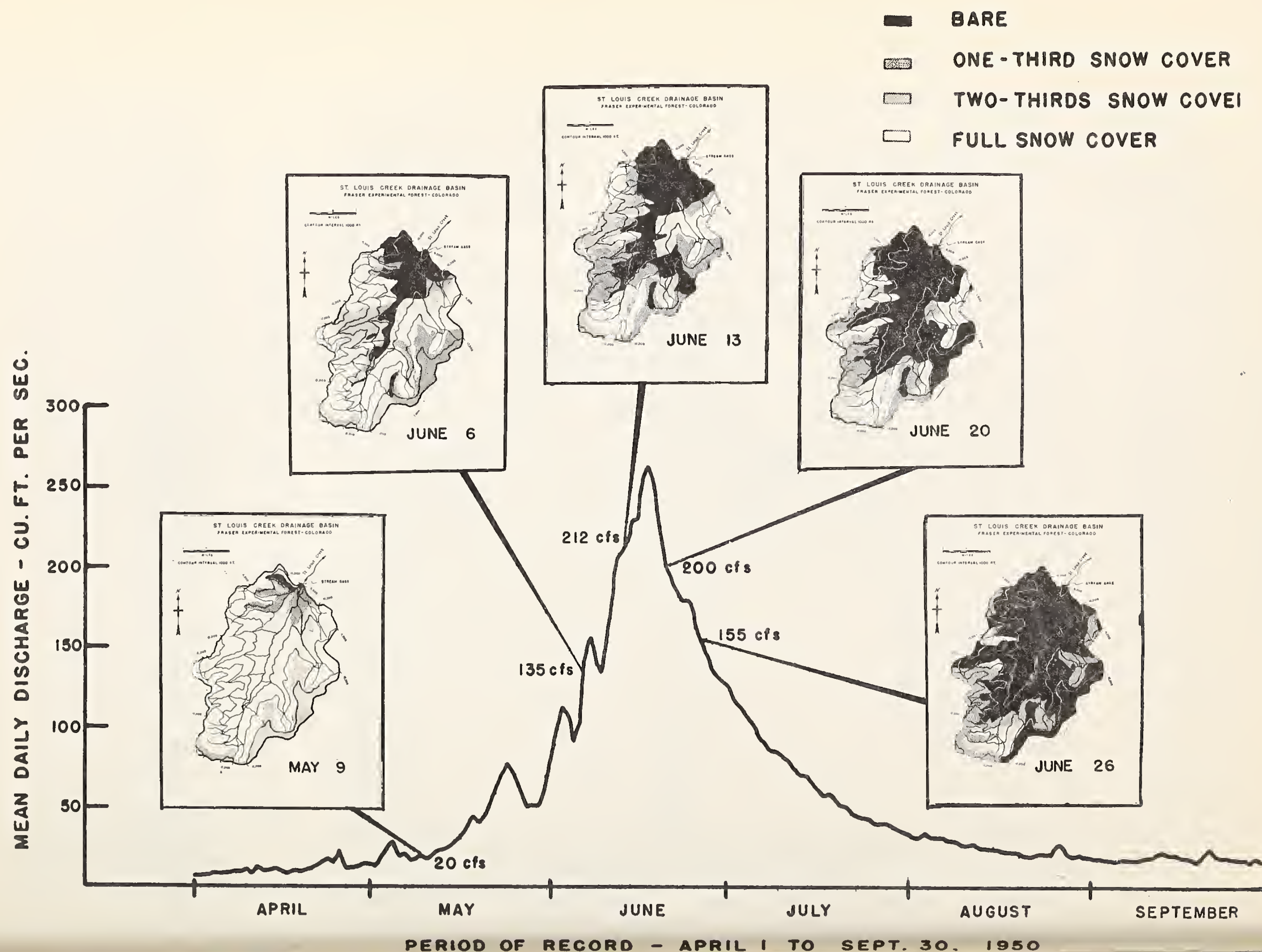


Figure 2.-- A, Percent of watershed bare of snow and cumulative stream discharge. B, Mean daily discharge, St. Louis Creek, 1950.


BARE
ONE-THIRD SNOW COVER
TWO-THIRDS SNOW COVEI
FULL SNOW COVER
ST. LOUIS CREEK DRAINAGE BASIN
FRASER EXPERIMENTAL FOREST - COLORADO
MAY 9
JUNE 6
JUNE 13
JUNE 20
JUNE 26
20 cfs
135 cfs
212 cfs
200 cfs
155 cfs
MEAN DAILY DISCHARGE - CU. FT. PER SEC.
300
250
200
150
100
50
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
PERIOD OF RECORD - APRIL 1 TO SEPT. 30. 1950

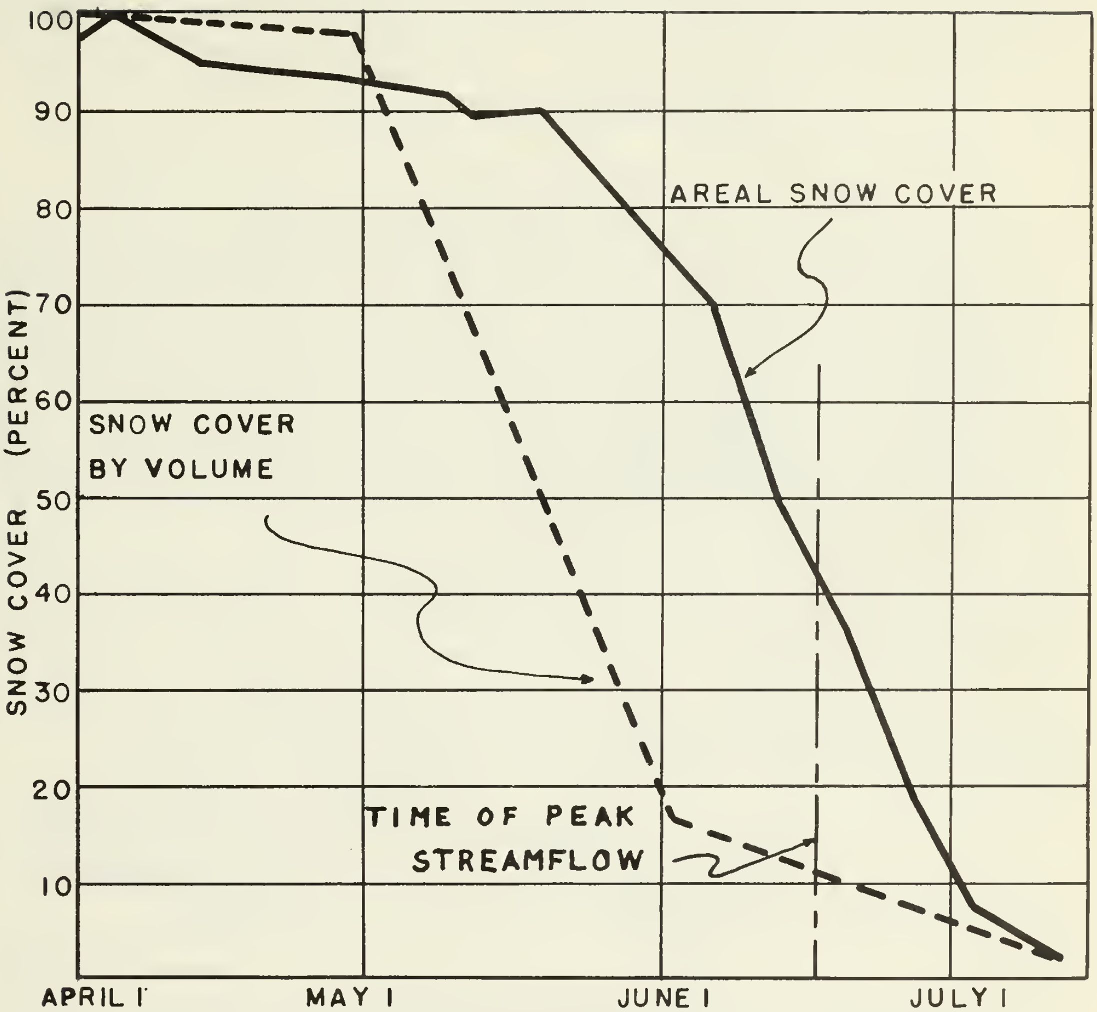


Figure 4.-- Areal snow cover compared with average water content of snow pack, St. Louis Creek watershed, 1950.

rise of St. Louis Creek is delayed several weeks from the time snowmelt begins, but it corresponds rather closely with the first appearance of bare ground on the watershed.

SOME POSSIBLE APPLICATIONS IN FORECASTING

Because this study was made during one year only, it does not provide a reliable basis for making short-term streamflow forecasts based on the extent of snow cover. However, if future observations substantiate the results obtained, there may be several important applications as indicated below.

Total Discharge During the Snowmelt Period

The general agreement between the watershed area bare of snow and the percent of total melt period discharge that had occurred by a given date is shown in table 1. This indicates the possibility of estimating total flow during the snowmelt period on the basis of the proportion of bare area. For example, the bare area on June 6 was 29.9 percent, indicating that approximately 29.9 percent of the flow during melt period had already left the watershed. Since the cumulative discharge between the beginning of melt season through June 6 was 4,437 acre-feet (fig. 2), the total flow during the melt period can be estimated by the proportion 4,437/29.9 = total flow/100 and the estimate of total flow is 14,839 acre-feet. This compares rather favorably with the actual discharge of 15,553 acre-feet. It should be emphasized, however, that several years of record are necessary before confidence can be placed in this relationship.

Table 1.-- Percentage of bare area and melt period streamflow

Date	Portion of watershed bare of snow	Portion of total melt period discharge that had left watershed
	Percent	Percent
April 1	2.3	0.1
4	0.0	0.4
14	5.1	1.8
27	6.5	4.1
May 9	8.3	7.0
12	10.8	7.8
19	10.0	10.9
June 6	29.9	28.5
13	50.8	43.8
20	63.7	64.8
27	81.3	80.2
July 3	92.8	89.8
12	97.9	100.0

Time of Peak Streamflow

For the year 1950, peak streamflow occurred when 58 percent of the watershed was bare of snow (fig. 2). It is possible that repeated observations would show that the date of peak streamflow is definitely correlated with the portion of the watershed bare of snow. If so, it may be possible to predict the date of peak streamflow.

Discharge at Peak Streamflow

Prediction of maximum daily discharge might also be possible if a definite relation can be established between discharge at the time a given percentage of bare area is reached and the peak discharge. For example, in 1950 the mean daily discharge when 16 percent of the area was bare was 70 c.f.s. This amounted to 26.6 percent of the 263 c.f.s. discharge that occurred on the peak day. If this relationship exists from year to year, then the peak flow could be estimated by dividing the discharge when 16 percent bare area is reached by 0.266. An early estimate of peak streamflow is extremely useful but difficult to obtain with reasonable accuracy; therefore this method seems worthy of further investigation.

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